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Satellite Image Processing Software for Value-Added Products

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Abstract : To extract value-added products which are important in scientific area and practical life, e.g. digital elevation models, ortho-rectified images and geometric corrected images, Satellite Technology Research Center at Korea Advanced Institute of Science and Technology has developed a satellite image processing software called "Valadd-Pro". In this paper, "Valadd-Pro" software is briefly introduced and its main components such as precise geometric correction, ortho-rectification and digital elevation model extraction component are described. The performance of "Valadd-Pro" software was assessed on 10m resolution 6000×6000 SPOT panchromatic images (60km×60km) using ground control points from GPS measurements. The height accuracy was measured by comparing our results with 100m resolution DTEDs[1)] produced by USGS and 60m resolution DEMs generated from digitized contours produced by National Geography Institute. Also, to show the superior performance of "Valadd-Pro" software, we compared the performance with that of commonly used PCI® commercial software. Based on the results, the geometric correction of "Valadd-Pro" software needs fewer ground control points than that of PCI® software and the ortho-rectification of "Valadd-Pro" software shows similar performance to that of PCI® software. In the digital elevation model extraction, "Valadd-Pro" software is two times more accurate and four times faster than PCI® software.

Key Words : Digital Elevation Model, Ortho-rectification, Precise geometric correction, SPOT.

1. Introduction

As the satellite technology advances and the resolution of satellite images increases, it is becoming easier to get satellite images in hand. However, satellite images without the value-added processing may be nothing but artistic painting. That is, in order to benefit from satellite images, we should extract and utilize the paramount information in scientific area and practical life from satellite images, e.g. digital elevation models and ortho-rectified images.

Because of the economical and industrial merits of satellite images, the satellite image processing techniques have been developed in advanced nations. However, in the interior, the highly expensive technical know-hows have been imported from overseas. Hence, to extract value-

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1) Digital Terrain Elevation Data - Standardized by the U.S. Geological Survey (USGS)

added products and acquire these techniques by oneself, the Satellite Technology Research Center (SaTReC) has developed a satellite image processing software package called "Valadd-Pro (VALue ADDed PROduct generation software)" for linear pushbroom type sensor.

"Valadd-Pro" software is composed of three practical main components, i.e. 1) Digital Elevation Model Extraction, 2) Precise Geometric Correction, and 3) Ortho-rectification. "Valadd-Pro" software employed a Kalman-filter-based satellite orbit estimator for the precise geometric correction and a smart backward transform for the ortho-rectification. The digital elevation model extraction component is the core component in "Valadd-Pro" software. By designing the stereo matching module based on the geometry of the linear pushbroom sensor and using intelligent interpolation scheme, the error and extraction time of digital elevation models are drastically minimized.

The Introduction to "Valadd-Pro" software is described in Section 2. In Section 3, 4 and 5, the precise geometric correction, the digital elevation model extraction and the ortho-rectification component of "Valadd-Pro" software, respectively, are explained briefly. In Section 6, the performance of "Valadd-Pro" software on 10m resolution 6000 × 6000 SPOT panchromatic images is summarized.

2. Value-Added Product Generation Software (Valadd-Pro)

"Valadd-Pro" is an integrated software package that generates value-added products (geometric corrected images, ortho-rectified images and digital elevation models) from satellite imagery. Considering the performance of the system, "Valadd-Pro" software was developed on the IRIX operating systems using C^{++} programming language.

"Valadd-Pro" software consists of several software components. Its components are listed as follows:

- Graphical User Interface (GUI) component
- SPIM (SPOT image format), HIPS, GeoTiff and RAW format image I/O component
- Histogram modification and zoom in/out, etc. image analysis component
- Digital Elevation Model extraction component
- Precise geometric correction component
- Ortho-rectification component
- Map projection component

One of the key issues of the software is convenience. Therefore, "Valadd-Pro" software includes the graphical user interface as shown in Fig. 1. Also, for the fast and true color display, the software utilizes OpenGL®library. For the graphical user interface design, the free software package called *fdesign* was used.

"Valadd-Pro" software supports various image formats such as SPIM, HIPS, GeoTiff and RAW. The major components of "Valadd-Pro" software will be described in next sections.

3. Precise Geometric Correction Component

In general, raw satellite images received from satellites have geometric distortions due to the rotation of the earth and its ellipsoidal shape, etc. Also, each pixel of satellite images does not have any information about the coordinates such as longitude and latitude. Hence, for the utilization of satellite images, ground coordinates should be

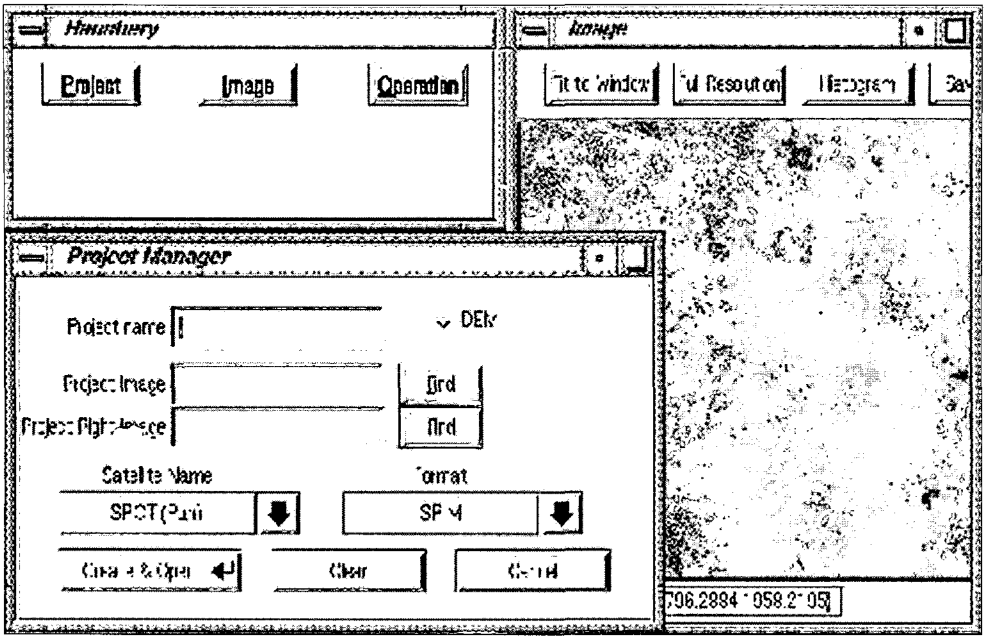

Fig. 1. Valadd-Pro Software Interface

assigned to each pixel, and the geometric distortions should be corrected (Shin and Lee, 1998).

In "Valadd-Pro"software, the precise geometric correction component consists of three major steps. 1) Ground control points (GCPs) acquisition. 2) Satellite sensor modeling, precise geometric correction and re-sampling. 3) Map projection.

Ground control points represent one point on image and its corresponding true coordinates on the ground. Although ground control points can be extracted from the vector map and so on, ground control points gathered using GPS (Global Positioning System) are more accurate. Hence, "Valadd-Pro"software provides an interface to read ground control points extracted using global positioning system from a file. Ground control points can also be inputted by clicking points on images and typing the ground coordinates in the ground control point input window.

Precise geometric correction is composed of geometric correction and precision correction. In geometric correction, the information such as orbit and attitude acquired from satellites or the orbit elements given by NORAD[2)] is used to correct satellite images. However, because the orbit and attitude information includes considerable errors, the method for accurate estimation of the velocity, position and attitude of a satellite from ground control points should be incorporated. This procedure is called precision correction. In "Valadd-Pro" software, to estimate the position, speed and attitude of the satellite, Kalman-filter-based satellite orbit estimator was employed.

Because the shape of the earth is ellipse and the map is on plain, converting satellite images into plain is necessarily needed. This is called map projection. In "Valadd-Pro"software, TM and

2) North American Aerospace Defense Command

UTM that are most common are supported. Also, most of datum and ellipsoid models are supported.

The performance of precise geometric correction algorithm will be explained in Section 6 of the paper. The full details of the performance analysis can be found in (Shin *et al.*, 1999).

4. Digital Elevation Model Extraction Component

Digital Elevation Model (DEM) is a digital data in which each point represents latitude, longitude and height. A digital elevation model has many applications such as geographic information system (GIS), flight simulations, urban planning, virtual reality and military ones. In these applications, the accuracy of the digital elevation models is important. There are various ways to produce digital elevation models from many types of sources such as airborne images, satellite images, etc. The use of satellite images for digital elevation models generation has the following advantages; 1) A scene covers a larger area. 2) Satellite images are naturally a digital data so that automation can be achieved. 3) Considering that many remote-sensing satellites are being launched, it is becoming easier to get satellite images in hand. However, despite of the advantages stated above, generating digital elevation models from satellite images suffers from several shortcomings -accuracy, coverage and execution time. In "Valadd-Pro" software, these problems can be overcome by adopting the stereo matching algorithm based on the epipolarity of linear push-broom sensor and the intelligent interpolation scheme (Lee *et al.*, 1999, Kim *et al.*, 1999).

Extracting digital elevation models consists of five steps; 1) Acquisition of ground control points. 2) Satellite sensor modeling. 3) Stereo matching based on the epipolarity of linear push-broom sensors. 4) DEM editing. 5) Interpolation. Satellite sensor modeling[3)] is a step estimating the geometry between a satellite sensor and the ground surface at the moment of satellite image acquisition, such as the position and attitude of a satellite. Stereo matching is a step finding the corresponding points in a stereo image pair. The elevation data generated by a sensor model and stereo matching could be erroneous. In DEM editing, these errors are corrected using a statistical model. After DEM editing, the elevation data are distributed randomly. Hence, elevation on a grid point must be calculated using interpolation. Each step is crucial to the accuracy and coverage of a digital elevation model. However, such steps used for images from aerial photos or still cameras are not adequate for the generation of digital elevation models from satellite images taken by linear push-broom sensors. Mainly because; 1) Sensor type is different. The position of a sensor changes line by line. 2) The noise due to haze and atmospheric distortion exists. 3) The intensities may be different if images are taken at different dates.

In "Valadd-Pro" software, we developed an accurate and robust digital elevation model extraction module for satellite image pairs. By considering the geometry of linear push-broom sensors, we could increase the accuracy of a stereo matching algorithm (Lee *et al.*, 1999). Also, by automatic DEM editing and intelligent

3) Considering the execution time, a sensor model of Orun and Natarazan (1994) is adapted.

interpolation scheme, we could acquire an accurate digital elevation models from the elevation data generated by a sensor model and stereo matching (Kim *et al.*, 1999).

The techniques used to maximize the performance of the stereo matching algorithm are as follows. Generally, the epipolarity relation can be established in stereo images that can be very useful. In the case of perspective images like airborne images, the epipolarity is represented as a linear equation. However, in linear push-broom type images, it is represented as a non-linear equation. Using such epipolarity, we can estimate the shape of a matching window and the local support region that help finding the accurate match points. If satellite image pairs have different viewing angles from each other, the size of a matching window on one scene differs from the size of that on the other scene that represents the same region. Thus, the window should be set differently for each scene considering the viewing angles of satellite images. a simple, but robust zero-mean normalized cross correlation is used as a measure of similarity between two matching windows. By integrating the techniques stated above using intelligent region growing strategy, we could minimize the execution time and increase the accuracy of the stereo matching algorithm.

The elevation data generated by a sensor model and stereo matching are distributed randomly. Hence, to acquire digital elevation models, we need to array the elevation data on the grid using interpolation. We have tested various interpolation schemes and Gaussian interpolator showed the best performance (Kim *et al.*, 1999). Intelligent interpolation schemes are further developed: (1) center-of-gravity (COG) and empty-center-index (ECI) which quantify how evenly distributed interpolants are within an interpolation radius. (2) Hole segmentation scheme to discern whether or not interpolation should take place in empty holes in stereo matching results. (3) Second segmentation scheme for removing noise-like features. By these schemes, we could remove severe blunders (Lee *et al.*, 1999) and the erroneous topography. The performance of our digital elevation model extraction component will be explained in section 6.

5. Ortho-Rectification

In "Valadd-Pro" software, ortho-rectification consists of three modules. 1) Satellite sensor modeling. 2) Converting three dimensional earth coordinate to two dimensional image coordinate using the sensor model. 3) Allocating intensities for each pixel.

For the sensor modeling, the same model with the digital elevation model generation component was employed. To convert three dimensional earth ground coordinate acquired from raw satellite image and digital elevation model to two dimensional image coordinates, "Valadd-Pro" software employed a smart backward transform algorithm (Kim *et al.*, 1999). In this algorithm, first, we estimate the attitude of a satellite, and then we assume the position of the satellite is constant in order to calculate the satellite position. In this way, non-linear equations can be linearized. Solving the linear equations, two dimensional image coordinates can be efficiently calculated.

Table 1. Performance analysis of Geometric correction and Ortho-rectification
(on SGI Octane 175MHz 1-CPU, 128Mbyte RAM)

	Valadd-Pro	PCI
Precision Correction Accuracy[6]	15 (meter)	15 (meter)
Ortho Rectification Accuracy	10 (meter)	10 (meter)

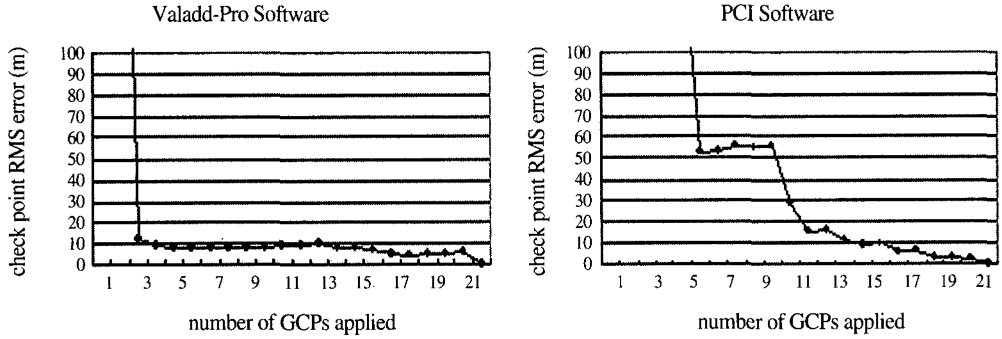

Fig. 2. Valadd-Pro and PCI Software Precise Geometric Correction Comparison

6. Performance Analysis of "Valadd-Pro" Software

One of the important stages of software development is quality assessment and validation. To analyze the performance of "Valadd-Pro" software, we tested our software on 10m resolution 6000 x 6000 SPOT panchromatic images (60km x 60km) by comparing with 100m-resolution digital terrain elevation data[4] (DTED) by USGS and 60m-resolution digital elevation model (DEM) generated from digitized contours produced by National Geography Institute. Also, to show the superior performance of "Valadd-Pro" software, we compared it with PCI® commercial software commonly used and whose performance was approved by NASA[5].

1) Analysis of Precise Geometric Correction Component

To analyze the performance of the precise geometric correction component, we tested using 33 ground control points for Seoul-Kyunggi area, 22 ground control points for Boryung-Buyeo area and 30 ground control points for Seosan-Dangjin area acquired using a global positioning system (GPS).

Fig. 2 shows the root mean square error of "Valadd-Pro" software and PCI® software based on the number of ground control points for Boryung-Buyeo area. In this figure, "Valadd-Pro" software has a highly accurate result using about 5 points - a small number of ground control points. However, PCI® software need at least 15 ground control points to acquire satisfactory results. In the Table 1, the average accuracy of three test areas is

4) Based on the comparision between GCPs and DTED, the mean error of DTED is 1.3 meters and its standard deviation is 6.5 meters.
5) National Aeronautics and Space Administration
6) The accuracy of precise geometric correction algorithm is referenced on Shin *et al.*, (1999)

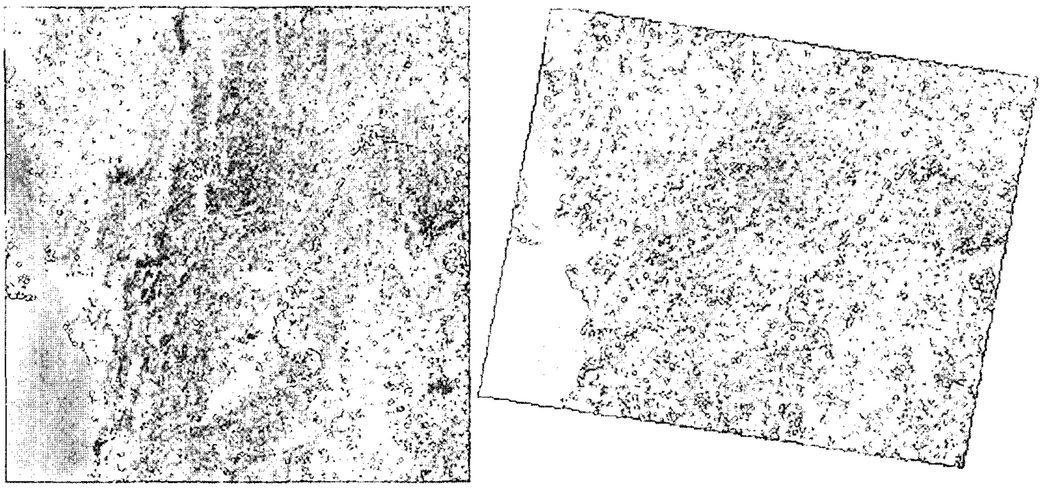

Fig. 3. Boryung Raw image(Left) and Geometric corrected Image(Right)

summarized.

Fig. 3 shows an image after precise geometric corretion for Boryung-Buyeo area using "Valadd-Pro" software.

2) Analysis of Digital Elevation Model Extraction Component

To analyze the performance of the digital elevation model extraction component, we tested using Seoul-Kyunggi area and Boryung-Buyeo area where geometric features e.g. the mountain, the sea, and the field, etc. are covered. Fig. 3 (left) is a raw image of Boryung-Buyeo area and Fig. 6 (left) is a raw image of Seoul-Kyunggi area.

The results of comparison using Seoul-Kyunggi area and Boryung-Buyeo area are summarized in Table 2. Fig. 4 and 5 show the digital elevation models of Boryung-Buyeo area and Seoul-Kyunggi area extracted using "Valadd-Pro" and PCI® software, respectively. Fig. 6 and 7 where high errors are represented brightly, show the difference between DEM extracted using "Valadd-Pro" and PCI® software and DTED. As shown in Table 2, Fig. 4, 5, 6 and 7, "Valadd-Pro" software is two times more accurate and four times faster than PCI® software in the accuray and extraction time of the digital elevation models.

Table 2. Performance analysis of Digital Elevation Model Extraction component (on SGI Octaine 175MHz 1-CPU, 128Mbyte RAM)

	Seoul-Kyunggi area			Boryung-Buyeo area		
DTED	Mean error	RMS error	Exec. time	Mean error	RMS error	Exec. time
Valadd-Pro	19.1m	33.6 m	40 m	9.4m	22.3m	35m
PCI®	38.0m	61.1m	2h 25m	36.0m	44.7m	1h 52m
Digitized DEM	Mean error	RMS error	Exec. time	Mean error	RMS error	Exec. time
Valadd-Pro	-	-	-	1.1m	22.3m	-
PCI®	-	-	-	30.0m	38.8m	-

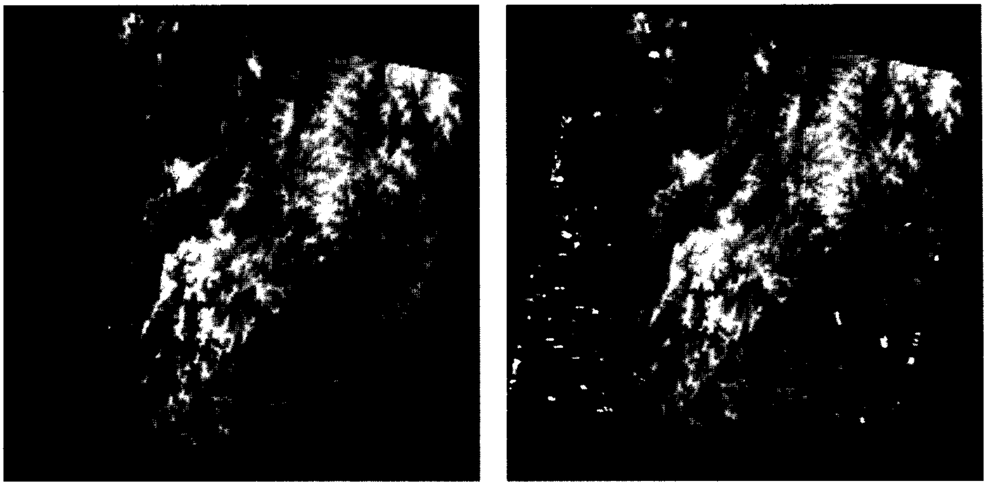

Fig. 4. Extracted Boryung DEM using Valadd-Pro(Left) and PCI(Right)

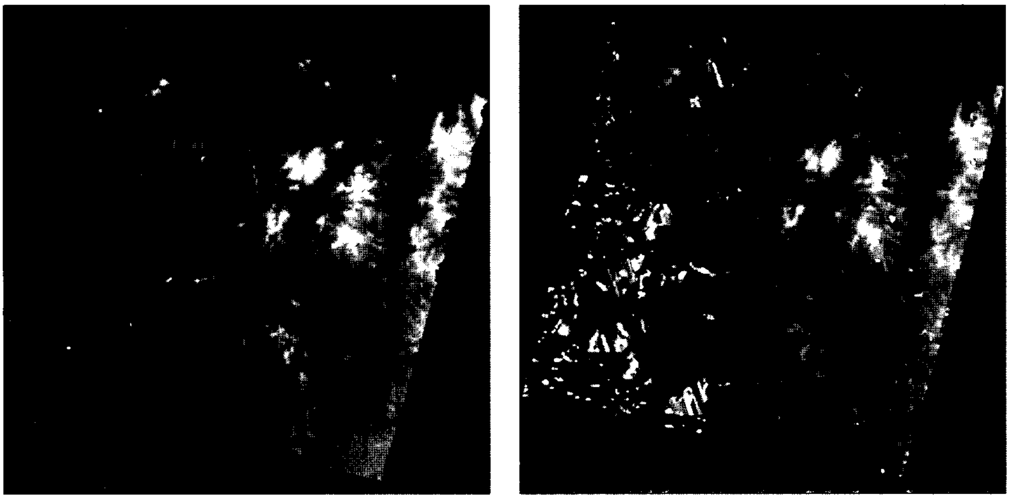

Fig. 5. Extracted Seoul DEM using Valadd-Pro(Left) and PCI(Right)

3) Analysis of Ortho-Rectification Component

In Table 1, the comparison of the ortho-rectification component between "Valadd-Pro" software and PCI® software is summarized. Also, Fig. 6 shows 6000 x 6000 raw SPOT Panchromatic image and its ortho-rectified image, respectively. As shown in Table 1 and Fig. 6, the ortho-rectification component of "Valadd-Pro" software is rivalry to those of PCI® software.

7. Conclusions

In order to benefit from satellite images, it is necessary to extract the paramount information in scientific world and practical life that can be

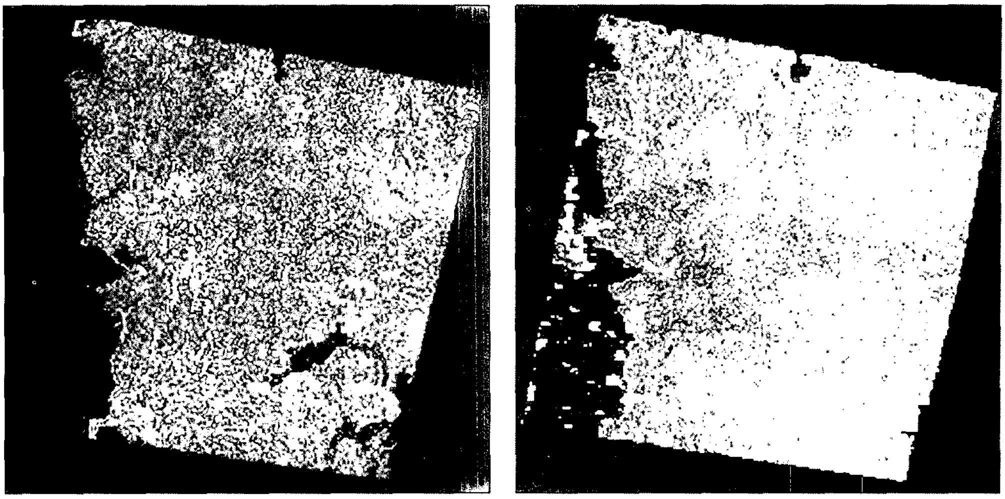

Fig. 6. |DEM-DTED| of Valadd-Pro(Left) and PCI(Right) on Boryung-Buyeo area

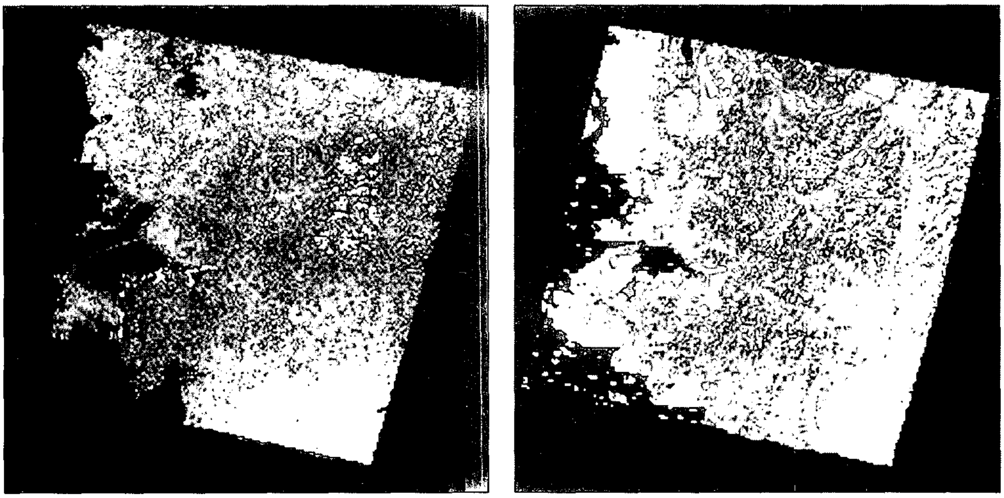

Fig. 7. |DEM-DTED| of Valadd-Pro(Left) and PCI(Right) on Seoul-Kyunggi area

extracted from satellite images. Therefore, the Satellite Technology Research Center (SaTReC) has developed a satellite image processing software called "Valadd-Pro". In this paper, "Valadd-Pro" software and its main components e.g. precise geometric correction, digital elevation model extraction, and ortho-rectification are described and their qualities are assessed.

In near future, after KOMPSAT-1 is launched, "Valadd-Pro" software will be tested on real EOC images of KOMPSAT-1 and be validated. Based on our current results, we expect to acquire satisfactory results.

Acknowledgements

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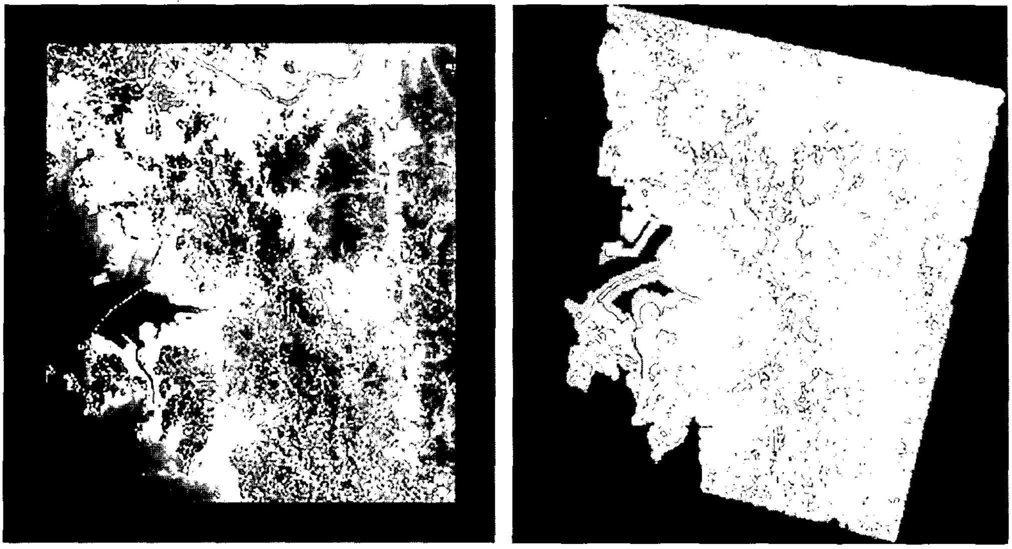

Fig. 8. Seoul raw image(Left) and Ortho rectified image(Right)

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